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LEARNING CONCEPT NETWORKS IN THE PHOTOSYNTHESIS BASED ON STUDENTS' COGNITIVE LEVELS

Soo-min Lim, Hyunju Chun, Hyonyong Lee, Youngshin Kim

Abstract. *An important educational goal is enabling students to learn scientific concepts. The scientific concepts learned in class are developed within students' cognitive structures. Despite the successful application of Semantic Network Analysis (SNA) to study these cognitive structures, there has been limited examination of students' concept networks based on their individual characteristics. Therefore, this study aims to evaluate the differences in students' characteristics based on their cognitive levels, which influence their thinking and behavior. To analyze these differences, this study compares concept and connected concept networks, focusing on photosynthesis, a challenging life sciences topic. The study's results indicate that students could not clearly distinguish concepts by subtopic, but there were changes in the concept network after class. Although the types and number of concepts students knew were similar depending on their cognitive level, the concept network structure differed. Additionally, some students could not distinguish between similar concepts. Thus, teachers are advised to differentiate between similar concepts during instruction and address personal variables such as students' cognitive levels.*

Keywords: *cognitive level, concept network, connected concept network, learning concept, photosynthesis*

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Introduction

Science education can be said to be a meaningful interaction between students, science teachers, and scientific content. Among these, it is very difficult to control student-related variables. Therefore, it is very important to understand how students perceive scientific content, think, and construct new concepts. When learning science content, most students learn with scientific concepts. Accordingly, the purpose of science education is to provide learners with an understanding of related concepts (You et al., 2002). Therefore, the science curriculum in the Republic of Korea aims to help students understand these concepts and develop their capabilities (MOE, 2022). The nature of scientific concepts makes it difficult to acquire knowledge independently; thus, students learn most concepts in class through teachers (Mallow, 1986; Pianta & Hamre, 2009; Schenke et al., 2017).

Concepts taught in class are delivered and absorbed by learners using their cognitive structure. At this time, most teachers have focused primarily on conveying conceptual knowledge without considering how learners understand and construct concepts in class (Widodo & Duit, 2002; Widodo et al., 2002). However, it is known that differences between the content taught by teachers and the level of understanding of students can lead to misconceptions and errors (Resnick & Klopfer, 1989). Therefore, in order for teachers to effectively present concepts, there was a need to analyze and present which concept structure (i.e., connection structure between concepts) is optimal for learning. In addition, because the learner's characteristics have a very great influence on learning, knowledge of how to transform and reorganize the content to suit the learners' characteristics and introduce it into classes has also been very important (Schulman, 2013). Therefore, it is necessary to classify and identify learning concepts according to the characteristics of students and to find ways to teach them.

Semantic Network Analysis (SNA) is widely used to analyze how learners recognize and construct concepts within their cognitive structures. It has been used to analyze the structure of concepts presented in science textbooks (Chung et al., 2018; Kim & Kwon, 2016) and the connection between curricula,

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textbooks, classes, and assessments (Kim et al., 2019). Some studies have analyzed concept structures according to students' listening types (Lim et al., 2020). In addition, network analysis has been used to study the connection between the concepts taught by teachers and those learned by students (Kim et al., 2023). However, these studies have failed to consider the learners' characteristics. Therefore, this study attempted to use the learners' cognitive level as a variable, which is an important factor in examining the learners' characteristics in science education.

Thinking and behavior are determined by cognitive level; Therefore, it is known that if a teacher fails to communicate scientific content in a way that matches students' cognitive levels, their teaching will be ineffective (Kim et al., 2024; Kwon et al., 2012). Although students' cognitive levels are crucial for planning and delivering teaching, there is a lack of research on the concepts students understand based on their cognitive level and how these concepts are structured. Therefore, this study analyzes the concepts students have learned and the relationships between them based on cognitive levels.

The knowledge gained through education is expected to be applied, continuously used, and maintained (Baldwin & Ford, 1988). In simpler terms, students are expected to actually use what they have learned, create change, and consistently display changed behavior or applied knowledge. Accordingly, it has been important to assess whether the knowledge acquired in class can be applied and maintained in other fields (Chance, 2009). Therefore, this study analyzes whether learned concepts were applied and maintained by investigating if they were learned immediately after class and following up on whether this knowledge was maintained four weeks later.

The topic of photosynthesis is used to compare students' concept networks based on their cognitive level. Photosynthesis is known as one of the most essential concepts because it is a fundamental concept for understanding metabolism, a basic biological phenomenon (Kijkuakul et al., 2006). It is a crucial topic in biology and is widely studied in elementary and lower and upper secondary schools in the Republic of Korea. It is also known to be a difficult topic for both learners and teachers (Ross et al., 2005) because it comprises complex concepts (Marmaroti & Galanpoulou, 2006). Therefore, it is an appropriate topic to analyze the connections and differences between concepts recognized by students after class through concept network analysis based on cognitive level.

Therefore, the purpose of this study was to obtain implications on how to present concepts in order to teach science topics that students find difficult depending on their characteristics. Accordingly, this study attempted to understand the structure of the concepts that students learned through classes on the topic of photosynthesis being covered in lower secondary schools of the Republic of Korea and suggest teaching - learning strategies utilizing this. The research questions of this study are as follows.

Depending on the variable of students' cognitive level, what is the difference in the network of students' learning concept immediately after conducting a class on the topic of photosynthesis and after 4 weeks of class? Photosynthesis is divided into three subtopics: reactants, products, and environmental factors. The concept structure learned by students is specifically developed through learning concept networks and connected concept networks. Through this, specific teaching - learning strategies and related implications are expected to be derived, helping teach students photosynthesis based on their cognitive levels.

Theoretical Background

Photosynthesis-related Content presented in the Curriculum

Currently, lower secondary schools in the Republic of Korea use the national curriculum, which was revised in 2015. The revised science curriculum teaches photosynthesis in the 6th, 8th, and 11th grades. The specific units presented in each grade are as follows (MOE, 2015): 'Structure and Function of Plants' (6th grade), 'Plants and Energy' (8th grade), and 'Cellular Respiration and Photosynthesis' (11th grade). The 'Structure and Function of Plants' unit helps students understand the individual functions of plant organs (e.g., roots, stems, leaves, and flowers) and that they are interconnected. The inquiry activity focuses on identifying photosynthetic products, and the key concepts are "transpiration" and "photosynthesis."

The 'Plants and Energy' unit focuses on understanding how plants create and use nutrients to obtain the necessary energy. The learning content related to photosynthesis includes 'the role of photosynthesis in producing nutrients,' 'substances necessary for photosynthesis,' and 'products.' The research activity explores the environmental factors that affect photosynthesis, and the key concepts are "the materials necessary for photosynthesis," "photosynthetic products," "factors affecting photosynthesis," and "production, storage, and use of photosynthetic products." Based on this, this study conducts research through classes focusing on three subtopics: 'photosynthesis reactants,' 'photosynthesis products,' and 'environmental factors.'

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The 'Cellular Respiration and Photosynthesis' unit helps students understand the metabolic relationship between cellular respiration and photosynthesis. Inquiry activities focus on researching the history of science related to photosynthesis and separating leaf pigments. The key concepts include "the structure and functions of chloroplast," "carbon fixation in photosynthesis," "the electron transport chain," and "light reaction through photosystems."

Students' Cognitive Levels in the Republic of Korea

Logical thinking was first introduced as a research topic in the Republic of Korea in 1978. It was analyzed using a questionnaire developed by Roadrangka et al. (1983), which Choi et al. (1985) translated into Korean. The determined cognitive levels of lower secondary school students in the Republic of Korea differed from study to study. Choi and Hur (1987) reported that 68% fell into the concrete operational stage of cognitive development, and only 4.4% were in the formal operation stage. Kim et al. (2002) reported that the concrete operational stage comprised 37.8%, the transitional stage encompassed 32.7%, and the formal operational stage accounted for 29.5%. Thus, combining previous studies, 23.0-63.1% of lower secondary school students in the Republic of Korea fall in the concrete operational stage, and 7.4-36% are in the formal operational stage.

Existing research in the Republic of Korea has been conducted on the differences and effects of scientific achievement and inquiry abilities depending on cognitive level, as well as on the relationship between cognitive levels and textbook content (Choi et al., 1985; Jeon & Park, 2014; Kim & Kim, 2009; Kim & Lee, 2001). Most of these studies showed that formal operational students have high science achievement and inquiry skills, and their teachers are effective. However, many studies have reported that Korea's science curriculum content was beyond students' cognitive levels (Kang et al., 2012; Kim et al., 2004; Jeong & Jang, 2017; Yang et al., 2024).

Research Methodology

Design

This study was conducted using a quantitative research design. The quantitative research design involves collecting quantitative statistical data on several variables studied (Cohen & Manion, 1994; Creswell, 2003). This study is a quantitative research design that collects data using questionnaires.

The independent variable in this study was students' cognitive levels, and the dependent variables were learning concept networks in the photosynthesis. Quantitative data of this study was collected by modifying and supplementing the questionnaire developed by Jeong and Kim (2011) and Lim et al. (2020) to suit the photosynthesis context. The study was conducted from May to July 2023. The participants were students from three lower secondary schools in a D metropolitan city and P city with a population of 2.5 million in the Republic of Korea and were 8th grade students who were not gifted or special students.

Under the scope of this study, the participants were invited through the science teacher at the lower secondary school. All of the participants and their parents in this study agreed to participate voluntarily. While collecting the data, the participants did not write their names while responding to the items.

Participants

The participants were from three lower secondary schools located in a D metropolitan city and P city with a population of 2.5 million in the Republic of Korea. The three schools were ranked mid-level as a result of the national academic achievement evaluation in the Republic of Korea. The researchers explained the purpose and method of the study in advance, which all of the participants and their parents agreed to. Participants comprised three science teachers (one male and two female) from three lower secondary schools and their 8^{th}-grade students (aged 13 and 14). One teacher had four years of teaching experience, and two had more than ten years; out of the three, two had completed master's degrees.

Students participating in the study were asked to fill out a questionnaire on either 'photosynthesis reactants,' 'photosynthesis products,' or 'environmental factors' to reduce problems caused by conducting the questionnaire multiple times. As a result, 104 participants (male: 50, female: 54) filled out questionnaires on 'photosynthesis reactants,' 102 (male: 45, female: 57) filled out 'photosynthesis products,' and 86 (male: 41, female: 45) filled out 'environmental factors.' Among these, students who left responses blank or responded indifferently to any of the cognitive level or photosynthesis learning concept questionnaires were excluded from the analysis. As a result, 98

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(male: 45, female: 53) students were analyzed for 'photosynthesis reactants,' 85 (male: 36, female: 49) for 'photosynthesis products,' and 68 (male: 28, female: 40) for 'environmental factors.' Likewise, the gender ratio was not biased towards one side. Table 1 is gender composition based on participants' cognitive level.

Table 1
Gender Composition based on Participants' Cognitive Level

	Concrete Operational Stage		Transition Stage		Formal Operational Stage		Total
	Male	Female	Male	Female	Male	Female	
Photosynthesis Reactants	27	27	13	17	5	9	98
Photosynthesis Products	20	28	11	15	5	6	85
Environmental Factors	14	24	11	11	3	5	68

Regarding students' cognitive levels, 54 (55.1%) were in the concrete operational group and 14 (14.3%) in the formal operational group for the 'photosynthesis reactants' questionnaire. For the 'photosynthesis products' questionnaire, 48 (56.5%) were in the concrete operational group, and 11 (13.0%) were in the formal operational group. For the 'environmental factors' questionnaire, 33 (55.9%) were in the concrete operational group, and 8 (11.8%) were in the formal operational group. In this study, students in the concrete operational stage account for 55.1-56.5%, and students in the formal operational stage comprise 11.8-14.3%, which is within the composition range of previous studies in the Republic of Korea.

Research conducted in connection with normal educational practice in schools and educational institutions determined and announced by the Minister of Health and Welfare with official permission from the head of the educational institution in accordance with Article 2 of the Elementary and Secondary Education Act and Article 2 of the Higher Education Act is research excluded from research on human subjects under the Bioethics Act (KoNIBP, 2018). In addition, the data collected to classify students' cognitive levels was used only for research purposes, and consent was obtained after notifying the school, students, and parents that students' personal information would not be collected or recorded.

Class Contents of Photosynthesis

Classes of photosynthesis were taught by the science teachers at each school according to the class plan of the respective schools. The classes took place from May to July 2023. The concept network for photosynthesis was classified into three subtopics for analysis: 'photosynthesis reactants,' 'photosynthesis products,' and 'environmental factors.' Each subtopic was covered in a separate session; thus, three sessions of classes with teaching concepts, including inquiry activities, were conducted.

The class of the 'photosynthesis reactants' covered the photosynthesis process, in which plants use light energy to create nutrients from carbon dioxide and water. The reason why photosynthesis is necessary was presented by comparing and explaining the differences in how animals and plants obtain the energy they need to live. By explaining the experiment on determining the substances necessary for photosynthesis by observing the color change of the BTB solution, the process of the experiment can be understood in connection with photosynthesis.

The class of the 'photosynthesis products' studied plants' glucose and oxygen production using light energy, carbon dioxide, and water. In class, the teacher explained an experiment where the starch produced through the photosynthesis process in Hydrilla verticillata leaves is observed, suggesting that photosynthesis occurs when glucose is converted into starch and temporarily stored in chloroplasts. The teachers also explained that oxygen is generated from photosynthesis using an experiment to collect and identify gas generated during photosynthesis.

The class of the 'environmental factors' examined the overall process of photosynthesis from previous classes to determine how the amount of photosynthesis is affected by environmental factors such as light intensity, carbon dioxide concentration, and temperature. The teacher explained an experiment measuring the time it takes for spinach leaves to rise depending on the number of lights turned on. Through this, the teacher helped students understand changes in photosynthesis based on light intensity. In addition, students were encouraged to think of experimental methods to determine changes in photosynthesis according to temperature changes and carbon dioxide concentration.

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Questionnaire

The photosynthesis learning concept questionnaire used in this study divided photosynthesis into three subtopics: 'photosynthesis reactants,' 'photosynthesis products,' and 'environmental factors.' These subtopics were modified from and supplemented by inspection tools used by Jeong and Kim (2011) and Lim et al. (2020) to suit the photosynthesis context. The questionnaire included subtopic names, learning objectives, related pictures, and simple examples of how to complete the questionnaire. After a class on each subtopic, students were asked to describe the related content they had learned. The questionnaires were open-ended so students could write freely, and an online format was used.

The students' cognitive level questionnaire used in this study was group assessment of logical thinking (GALT) test that has been widely used to measure logical thinking levels in the field of education. The Cronbach's alpha reliability coefficient of the test was recorded at .52, which is considered moderate for use in the study (Lay, 2009). The GALT test used in this study consists of twelve items in six subscales measuring logical operations, as noted by Roadrangka et al. (1983). The subscale covers conservation reasoning, proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. It comprises 12 items, two for each subscale.

Data Collection and Analysis

The cognitive level questionnaire was administered to students before class. After the teacher taught students about the photosynthesis, the students were administered the photosynthesis learning concept questionnaire. This questionnaire was administered to students again four weeks later. The cognitive level questionnaire was administered under the supervision of the homeroom teacher, and the testing took up to 25 minutes.

The photosynthesis learning concept questionnaire was administered online using tablets provided by each school under the supervision of the instructor who taught the photosynthesis class. It took students approximately 10 to 15 minutes to fill it out.

The cognitive level questionnaire was structured as follows. For questions one to ten, respondents had to provide both the correct answer and the reasoning behind it. For questions eleven and twelve, only those that listed all possible cases were treated as correct. Regarding scoring, the cognitive level was divided as follows: four or fewer items classified the respondent into the concrete operational stage, five to seven items classified the respondent into the transitional stage, and eight to twelve items classified the respondent into the formal operational stage.

The photosynthesis learning concept questionnaires were classified by subtopic and transcribed sentence by sentence. The transcribed content was saved as a text (.txt) file. To compare and analyze the concept structure according to students' cognitive levels, the levels were divided into the concrete operational stage, the transitional stage, and the formal operational stage, and the sentences presented in the photosynthesis learning concept questionnaire were saved as separate text files (.txt).

The transcribed files were pre-processed using the NetMiner 4.0 program to extract only noun-type concepts. The concepts not needed for analysis were removed through pre-processing (Oh et al., 2022). Among the extracted concepts, those that were not scientific were excluded, and those with similar meanings were collected and unified. Through this process, 73 concepts were selected.

To avoid researcher subjectivity, five biology education experts who are current science teachers in lower and upper secondary schools and hold a teacher's license and doctoral degree in biology education were asked to select the concept. Based on this, 47 analysis concepts were selected by at least three out of five teachers.

Based on these selected concepts, the concept structure was visualized using the NetMiner 4.0 program. The 1-mode network was used as a concept network to analyze the structure of concepts recognized by students, and the 2-mode connection concept network analyzed connection concepts. In the case of a 1-mode network, the size of the node increases proportionally depending on the frequency, and the thickness of the link increases proportionally according to the frequency of co-occurrence between concepts. Furthermore, the eigenvector centrality index analyzes how important and influential connected concepts are on the network (Bonacich, 2007); thus, it is mainly used when selecting key concepts on a concept network.

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Research Results

Concept Networks

Photosynthesis Reactants

The concept network for 8th-grade students' understanding of 'photosynthesis reactants' after the initial class and four weeks later based on cognitive level is shown in Figure 1. The frequency and eigenvector centrality index of students' learning concepts of 'photosynthesis reactants' after the initial class and four weeks later based on cognitive level is shown in Table 2.

Students in the concrete operational stage identified 21 concepts after the initial class (Figure 1a) and 20 concepts four weeks later (Figure 1b). In the network of concrete operational students after the initial class, "Photosynthesis" was connected with "plant," "leaf," "nutrition," "light energy," "oxygen," "stoma," and "hydrilla verticillata." "Light energy" was connected with "water," "plant," "photosynthesis," "oxygen," and "stoma." "Carbon dioxide" was connected with "absorption," "bromothymol blue," "stoma," "water," and "leaf." In the network of concrete operational students four weeks later, non-scientific concepts such as "glucose" were presented with high frequency. The network was structured around "photosynthesis," "carbon dioxide," and "light energy." "Photosynthesis" was connected with "chloroplast," "plant," "light energy," "oxygen," and "starch." "Carbon dioxide" was connected with "bromothymol blue," "light energy," "water," "glucose," "starch," and "photosynthesis." "Light energy" was connected with "carbon dioxide concentration," "plant," "bromothymol blue," and "photosynthesis."

Table 2
'Photosynthesis Reactants' Concept Frequency and Eigenvector Centrality based on Cognitive Level

Concept	Concrete Operational Stage				Transition Stage				Formal Operational Stage			
	After Class		Four Weeks Later		After Class		Four Weeks Later		After Class		Four Weeks Later	
	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.
Photosynthesis	66	.256	47	.169	57	.232	40	.252	28	.102	25	.426
Carbon dioxide	64	.257	43	.648	48	.651	31	.587	20	.631	16	.493
Water	46	.628	34	.649	29	.648	21	.567	15	.578	10	.394
Light energy	41	.302	41	.331	31	.270	34	.513	21	.482	18	.534
Glucose	28	.026	22	.059	27	.019	12	.025	11	.010	7	.006
Oxygen	19	.074	14	.049	12	.029	14	.025	7	.039	5	.002

* E: Eigenvector centrality index

Students in the transition stage identified 24 concepts after their initial class (Figure 1c) and 20 concepts four weeks later (Figure 1d). In the network of transitional students after the initial class, "Carbon dioxide" was connected with "stoma," "photosynthesis," "water," "plant," and "light energy." "Photosynthesis" was connected with "leaf," "glucose," "conversion," "hydrilla verticillata," "shift," "light energy," "plant," "absorption," and "carbon dioxide." "Light energy" was connected with "photosynthesis," "water," "absorption," "temperature," and "hydrilla verticillata." "Glucose" was connected with "starch," "oxygen," "hydrilla verticillata," and "photosynthesis." It could be seen that non-scientific concepts such as "glucose" existed at the center of the network. And in the network of transitional students four weeks later, non-scientific concepts such as "oxygen" were still presented with a high frequency. "Photosynthesis" was connected with "water," "carbon dioxide," "oxygen," "hydrilla verticillata," and "light energy." "Light energy" was connected with "photosynthesis," "water," "carbon dioxide," "glucose," "plant," and "light energy." "Carbon dioxide" was connected with "stoma," "photosynthesis," "light energy," "water," and "temperature."

Students in the formal operational stage identified 17 concepts after the initial class (Figure 1e) and 16 concepts four weeks later (Figure 1f). In the network of formal operational students after the initial class, scientific concepts such as "photosynthesis," "light energy," and "carbon dioxide" were located at the center of the network due to their high frequency and eigenvector centrality. "Photosynthesis" was connected with "chloroplast," "hydrilla verticillata," "light energy," "carbon dioxide," and "plant." "Light energy" was connected with "hydrilla verticillate," "photosynthesis,"

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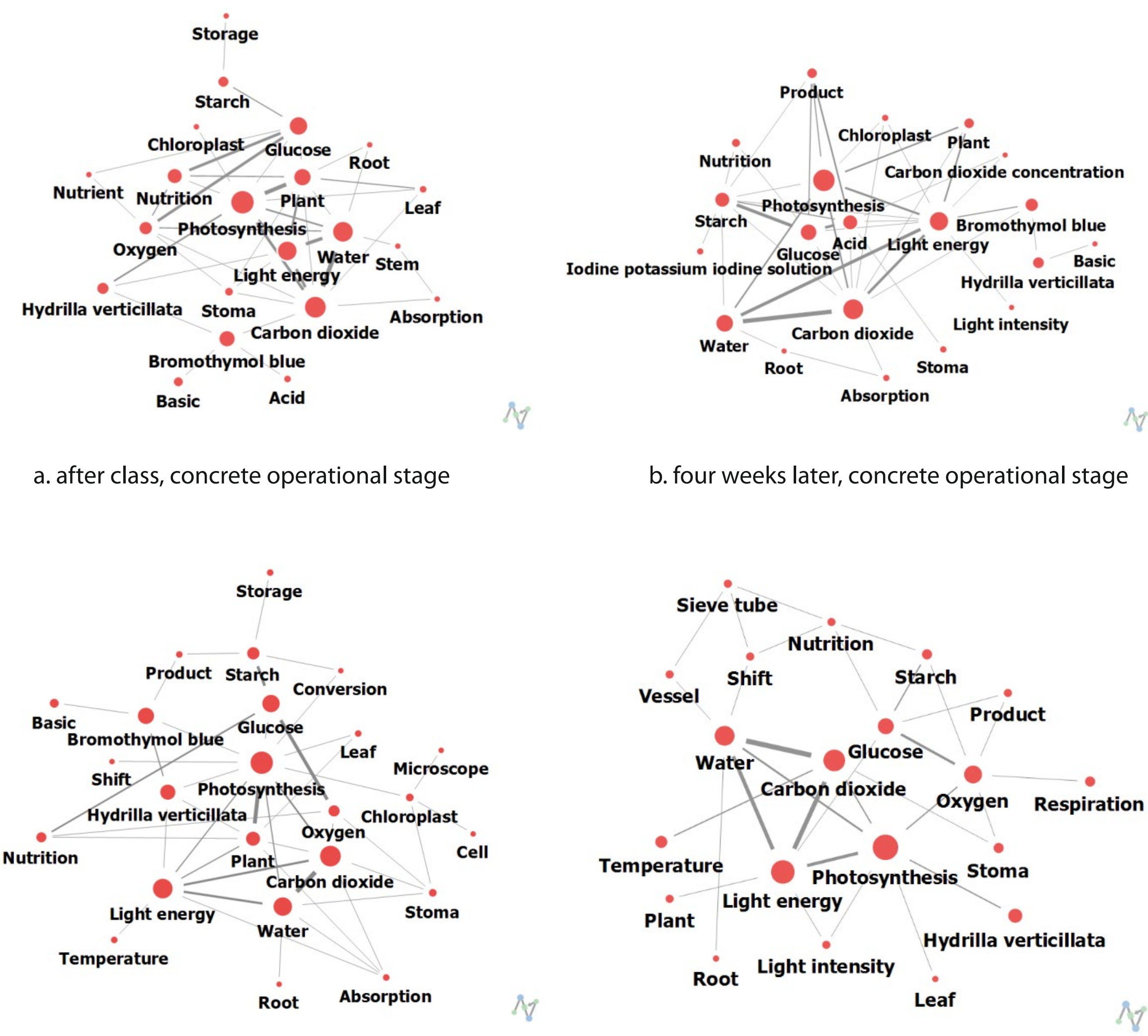
"water," "carbon dioxide," and "plant," Carbon dioxide was connected with "water," "hydrilla verticillata," "light energy," "photosynthesis," and "oxygen." In the network of formal operational students four weeks later, scientific concepts such as "photosynthesis," "light energy," and "carbon dioxide" were still formed around. "Photosynthesis" was connected with "hydrilla verticillata," "storage," "chloroplast," "plant," "light energy," and "nutrition." "Light energy" was connected with "carbon dioxide," "water," "leaf," "light intensity," "plant," and "photosynthesis." "Carbon dioxide" was connected with "temperature," "water," and "light energy."

Figure 1
'Photosynthesis Reactants' Concept Networks based on Cognitive Level



a. after class, concrete operational stage

b. four weeks later, concrete operational stage

c. after class, transition stage

d. four weeks later, transition stage

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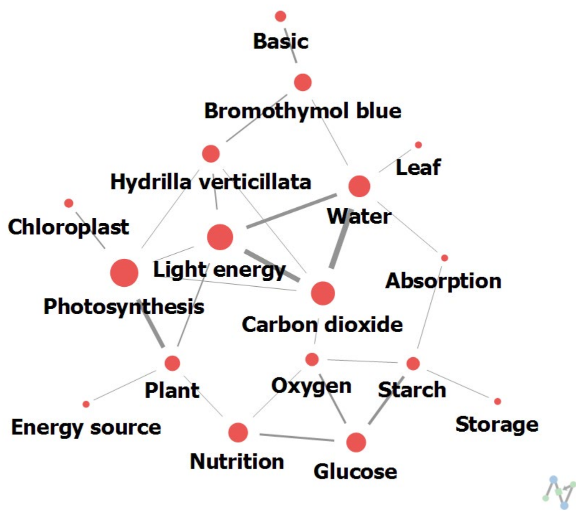
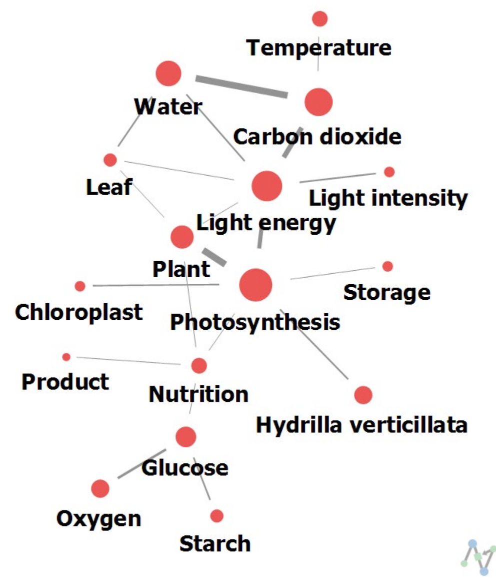


e. after class, formal operational stage



f. four weeks later, formal operational stage

Photosynthesis Products

Eighth-grade students' concept network for 'photosynthesis products' after the initial class and four weeks later based on cognitive level is shown in Figure 2. And the frequency and eigenvector centrality index of students' learning concepts of 'photosynthesis products' after the initial class and four weeks later based on cognitive level is shown in Table 3.

Students in the concrete operational stage identified 21 concepts after the initial class (Figure 2a) and 17 concepts four weeks later (Figure 2b). The network of concrete operational students after the initial class was structured around "photosynthesis," "starch," "glucose," and "oxygen". "Photosynthesis" was connected with "oxygen," "starch," "carbohydrate," "chloroplast," "plant," and "carbon dioxide." "Glucose" was connected with "starch," "leaf," "product," "plant," and "oxygen." "Starch" was connected with "carbohydrate," "hydrilla verticillata," "iodine potassium iodine solution," "blue," "glucose," and "oxygen." "Oxygen" was connected with "starch," "photosynthesis," "water," and "carbon dioxide". The network of concrete operational students four weeks later was structured around "photosynthesis," "glucose," "oxygen," "starch," and "product".

Table 3
'Photosynthesis Products' Concept Frequency and Eigenvector Centrality based on Cognitive Level

Concept	Concrete Operational Stage				Transition Stage				Formal Operational Stage			
	After Class		Four Weeks Later		After Class		Four Weeks Later		After Class		Four Weeks Later	
	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.
Photosynthesis	37	.206	36	.068	42	.371	37	.140	20	.384	16	.265
Starch	27	.475	16	.323	23	.118	20	.331	13	.413	7	.216
Glucose	23	.490	34	.608	27	.310	26	.613	10	.367	10	.471
Oxygen	22	.491	18	.505	15	.231	18	.514	12	.274	11	.442
Chloroplast	17	.093	10	.017	10	.161	8	.056	12	.325	6	.139
Light energy	16	.098	10	.026	24	.371	11	.036	6	.196	5	.280

* E: Eigenvector centrality index

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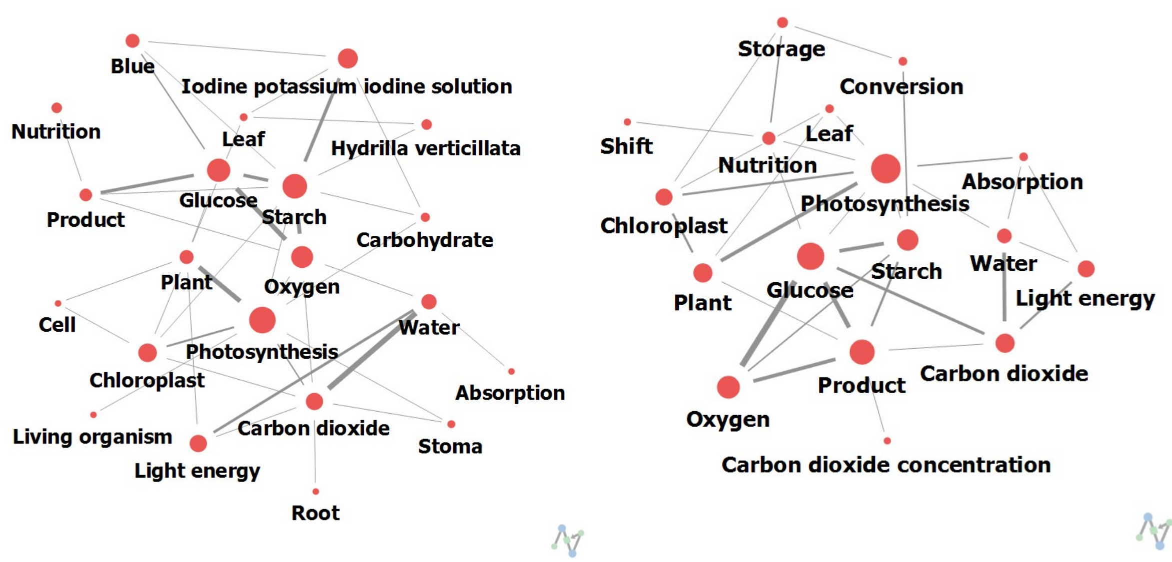
Students in the transition stage identified 19 concepts after the initial class (Figure 2c) and 21 concepts four weeks later (Figure 2d). The network of transitional students after the initial class was structured around "water," "plant," "light energy," and "glucose". "Water" and "light energy," which are not scientific concepts, were located at the center. "Water" was connected with "plant," "absorption," "glucose," "light energy," and "carbon dioxide." "Light energy" was connected with "carbon dioxide," "photosynthesis," "water," "plant," and "glucose." "Glucose" was connected with "oxygen," "light energy," "water," "nutrition," "product," and "starch." "Starch" was connected with "storage," "chloroplast," "iodine potassium iodine solution," "product," "glucose," and "nutrition." The network of transitional students four weeks later, was structured around "photosynthesis," "glucose," and "starch." "Photosynthesis" was connected with "light energy," "chloroplast," "leaf," "glucose," "chlorophyll," and "plant." "Glucose" was connected with "starch," "product," "leaf," and "photosynthesis." "Starch" was connected with "photosynthesis," "storage," "glucose," and "blue."

Students' formal operational stage identified 19 concepts after class (Figure 2e) and 19 concepts four weeks later (Figure 2f). The network of formal operational students after the initial class was structured around "starch," "photosynthesis," "glucose," and "chloroplast. "Photosynthesis" was connected with "chloroplast," "plant," "light energy," and "blue." "Starch" was connected with "chloroplast," "plant," "nutrition," "glucose," "oxygen," and "carbon dioxide." "Glucose" was connected with "starch," "nutrition," "product," and "oxygen." "Chloroplast" was connected with "plant," "photosynthesis," "iodine potassium iodine solution," "water," and "carbon dioxide." The network of formal operational students four weeks later was structured around "photosynthesis," "oxygen," and "glucose". "Photosynthesis" was connected with "plant," "storage," "chloroplast," and "light energy." "Oxygen" was connected with "starch," "product," "carbon dioxide," "glucose," "nutrition," and "stoma." "Glucose" was connected with "oxygen," "nutrition," "water," "carbon dioxide," "product," and "starch."

Figure 2
'Photosynthesis Products' Concept Network based on Cognitive Level



a. after class, concrete operational stage

b. four weeks later, concrete operational stage

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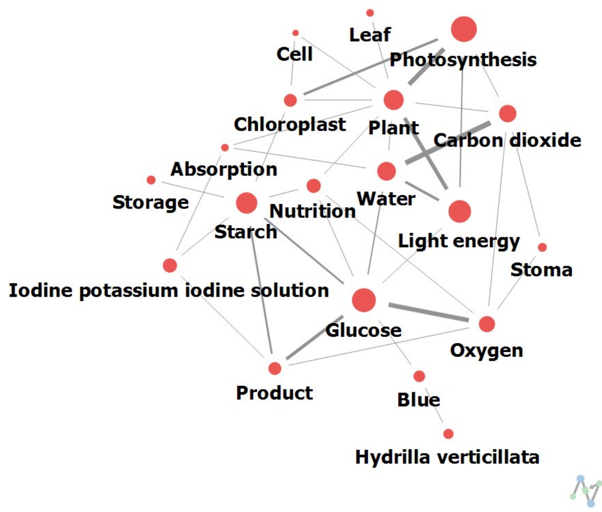
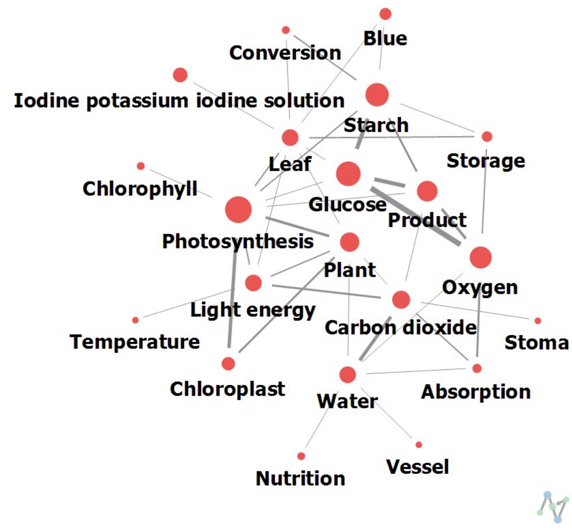
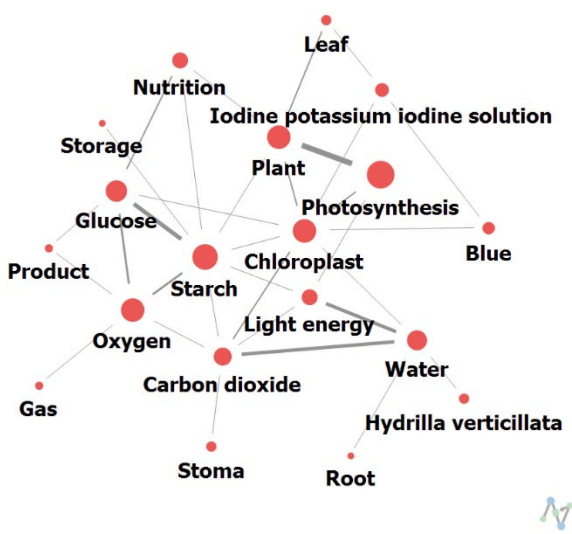


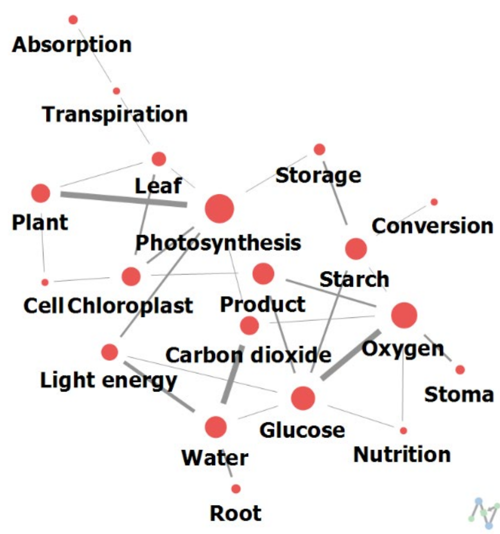
c. after class, transition stage



d. four weeks later, transition stage



e. after class, formal operational stage



f. four weeks later, formal operational stage

Environmental Factors

Eighth-grade students' concept network for 'environmental factors' after the initial class and four weeks later based on cognitive level is shown in Figure 3. The frequency and eigenvector centrality index of students' learning concepts of 'environmental factors' after the initial class and four weeks later based on cognitive level is shown in Table 4.

Students in the concrete operational stage identified 18 concepts after the initial class (Figure 3a) and 16 concepts four weeks later (Figure 3b). The network of concrete operational students after the initial class was structured around "photosynthesis," "light energy," "light intensity," and "carbon dioxide." "Photosynthesis" was connected with "oxygen," "plant," "light energy," "carbon dioxide," and "temperature." "Light energy" was connected with "water," "carbon dioxide," "light intensity," "carbon dioxide concentration," "plant," and "photosynthesis." "Light intensity" was connected with "temperature," "light energy," and "carbon dioxide concentration." "Carbon dioxide" was connected with "glucose," "photosynthesis," "water," "light energy," and "temperature." And the network of concrete operational

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students four weeks later was structured around "photosynthesis," "light energy," "light intensity," and "carbon dioxide." "Light energy" was connected with "light intensity," "carbon dioxide concentration," "photosynthesis," and "carbon dioxide." "Photosynthesis" was connected with "light energy," "temperature," "carbon dioxide," "oxygen," and "light intensity." "Light intensity" was connected with "light energy," "carbon dioxide concentration," "temperature," "absorption," and "oxygen."

Table 4
'Environmental Factors' Concept Frequency and Eigenvector Centrality based on Cognitive Level

Concept	Concrete Operational Stage				Transition Stage				Formal Operational Stage			
	After Class		Four Weeks Later		After Class		Four Weeks Later		After Class		Four Weeks Later	
	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.
Photosynthesis	38	.148	29	.158	48	.058	46	.133	24	.111	17	.088
Light energy	38	.621	36	.671	42	.688	32	.661	17	.671	11	.654
Light intensity	22	.574	23	.658	28	.685	28	.675	12	.667	12	.690
Carbon dioxide	21	.318	16	.165	17	.066	10	.037	11	.234	6	.019
Oxygen	17	.016	13	.063	13	.030	5	.000	6	.008	3	.005
Temperature	15	.114	23	.126	28	.133	27	.189	10	.008	7	.130

* E: Eigenvector centrality index

Students in the transition stage identified 15 concepts after the initial class (Figure 3c) and 18 concepts four weeks later (Figure 3d). The network of transitional students after the initial class was structured around "photosynthesis" and "light energy." "Photosynthesis" was connected with "chloroplast," "plant," "light energy," and "carbon dioxide." "Light energy" was connected with "photosynthesis," "plant," "water," and "glucose." And the network of transitional students four weeks later was structured around "photosynthesis," "light intensity," "light energy," and "temperature." "Photosynthesis" was connected with "plant," "temperature," "light intensity," "carbon dioxide," and "light energy." "Light energy" was connected with "chloroplast," "carbon dioxide concentration," "light intensity," and "photosynthesis." "Light intensity" was connected with "temperature," "carbon dioxide," "carbon dioxide concentration," "light energy," and "photosynthesis." "Temperature" was connected with "carbon dioxide," "carbon dioxide concentration," "photosynthesis," and "light intensity." Meanwhile, "chlorophyll" and "storage" were not connected to other concepts.

Students in the formal operational stage identified 11 concepts after the initial class (Figure 3e) and 14 concepts four weeks later (Figure 3f). The network of formal operational students after the initial class was structured around "photosynthesis," "light energy," "light intensity," and "carbon dioxide." "Photosynthesis" was connected with "plant" and "light energy." "Light energy" was connected with "light intensity," "carbon dioxide concentration," and "water." "Light intensity" was connected with "carbon dioxide concentration," "light energy," and "carbon dioxide." "Carbon dioxide" was connected with "plant," "light intensity," and "water." And the network of formal operational students four weeks later was structured around "photosynthesis," "light intensity," and "light energy." "Photosynthesis" was connected with "temperature," "light energy," "carbon dioxide," "product," and "nutrition." "Light intensity" was connected with "temperature," and "carbon dioxide concentration" was connected with "light energy." "Light energy" was connected with "water," "light intensity," "temperature," and "photosynthesis."

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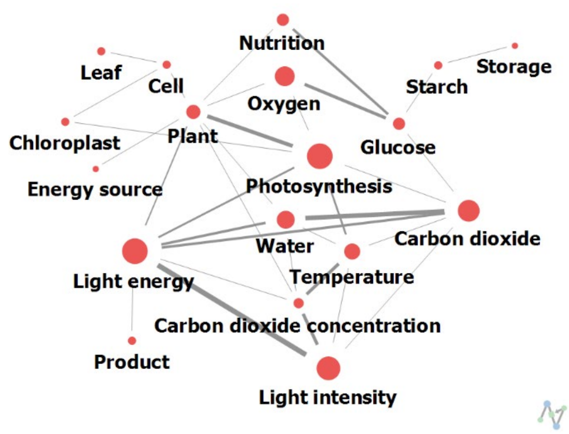
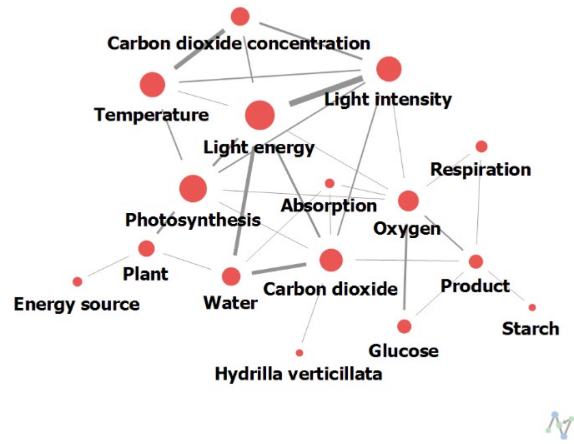
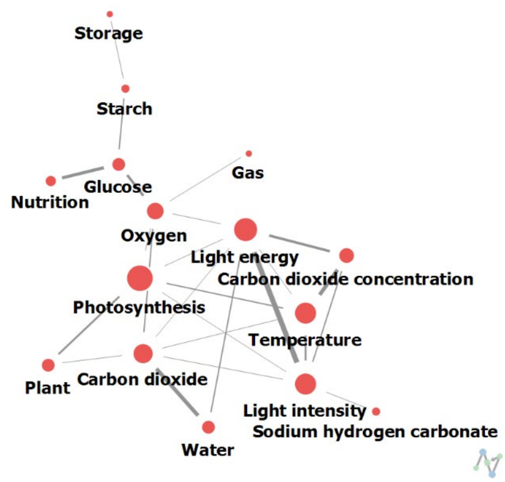
Figure 3
'Environmental Factors' Concept Networks based on Cognitive Level



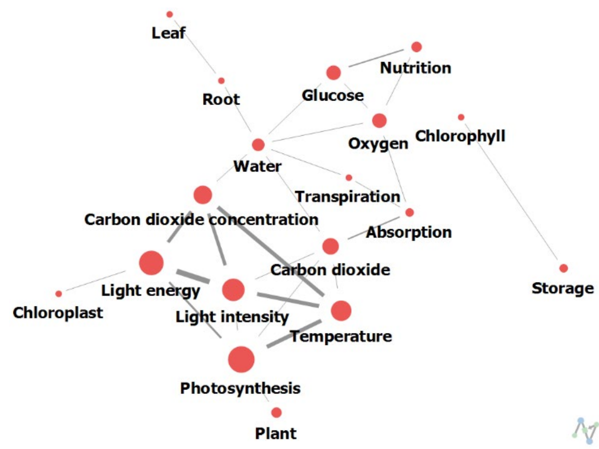
a. after class, concrete operational stage



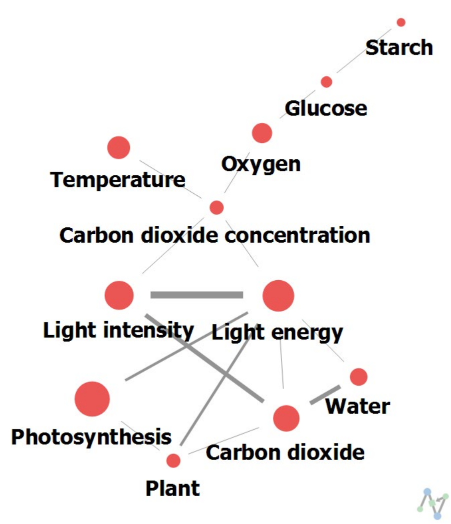
b. four weeks later, concrete operational stage



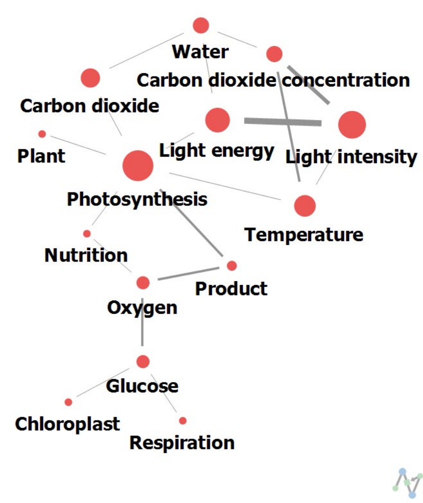
c. after class, transition stage



d. four weeks later, transition stage



e. after class, formal operational stage



f. four weeks later, formal operational stage

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Photosynthesis

Eighth-grade students' concept network for 'photosynthesis' after the initial class and four weeks later based on cognitive level is shown in Figure 4. And the frequency and eigenvector centrality index of students' learning concepts of 'photosynthesis' after the initial class and four weeks later based on cognitive level is shown in Table 5.

Students in the concrete operational stage identified 31 concepts after the initial class (Figure 4a) and 27 concepts four weeks later (Figure 4b). The network of concrete operational students after the initial class was structured around "photosynthesis," "carbon dioxide," and "light energy." "Photosynthesis" was connected with "plant," "chloroplast," "glucose," "starch," and "light intensity." "Carbon dioxide" was connected with "water," "plant," "oxygen," "absorption," "root," and "stoma." "Light energy" was connected with "plant," "photosynthesis," "carbon dioxide," "water," and "light intensity." And the network of concrete operational students four weeks later was structured around "carbon dioxide," "photosynthesis," and "light energy." "Carbon dioxide" was connected with "water," "photosynthesis," "light energy," "glucose," and "oxygen." "Photosynthesis" was connected with "plant," "nutrition," "starch," "glucose," and "carbon dioxide." "Light energy" was connected with "water," "photosynthesis," "absorption," "carbon dioxide," and "oxygen."

Table 5
'Photosynthesis' Concept Frequency and Eigenvector Centrality based on Cognitive Level

Concept	Concrete Operational Stage				Transition Stage				Formal Operational Stage			
	After Class		Four Weeks Later		After Class		Four Weeks Later		After Class		Four Weeks Later	
	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.	Freq.	E.
Photosynthesis	141	.246	112	.197	147	.250	123	.289	72	.186	58	.427
Carbon dioxide	101	.620	71	.571	81	.564	53	.448	38	.549	28	.405
Light energy	95	.345	87	.424	97	.389	77	.576	44	.513	34	.535
Water	76	.614	49	.551	55	.577	36	.395	28	.522	21	.389
Glucose	61	.051	60	.185	61	.104	43	.077	23	.043	20	.105
Oxygen	58	.099	45	.147	40	.109	37	.076	25	.057	19	.088

* E: Eigenvector centrality index

Students in the transition stage identified 30 concepts after the initial class (Figure 4c) and 29 concepts four weeks later (Figure 4d). The network of transitional students after the initial class was structured around "water," "light energy," and "carbon dioxide." And the network of transitional students four weeks later was structured around "photosynthesis," "light energy," and "carbon dioxide."

Students in the formal operational stage identified 26 concepts after the initial class (Figure 4e) and 24 concepts four weeks later (Figure 4f). The network of formal operational students after the initial class was structured around "photosynthesis," "light energy," and "carbon dioxide." And the network of formal operational students four weeks later was structured around "photosynthesis," "light energy," "water," and "carbon dioxide." "Photosynthesis" was connected with "light energy," "plant," "chloroplast," and "carbon dioxide." "Light energy" was connected with "light intensity," "photosynthesis," "water," "carbon dioxide," "plant," and "glucose." "Water" was connected with "light energy," "carbon dioxide concentration," "leaf," and "carbon dioxide." "Carbon dioxide" was connected with "light intensity," "water," "photosynthesis," and "oxygen."

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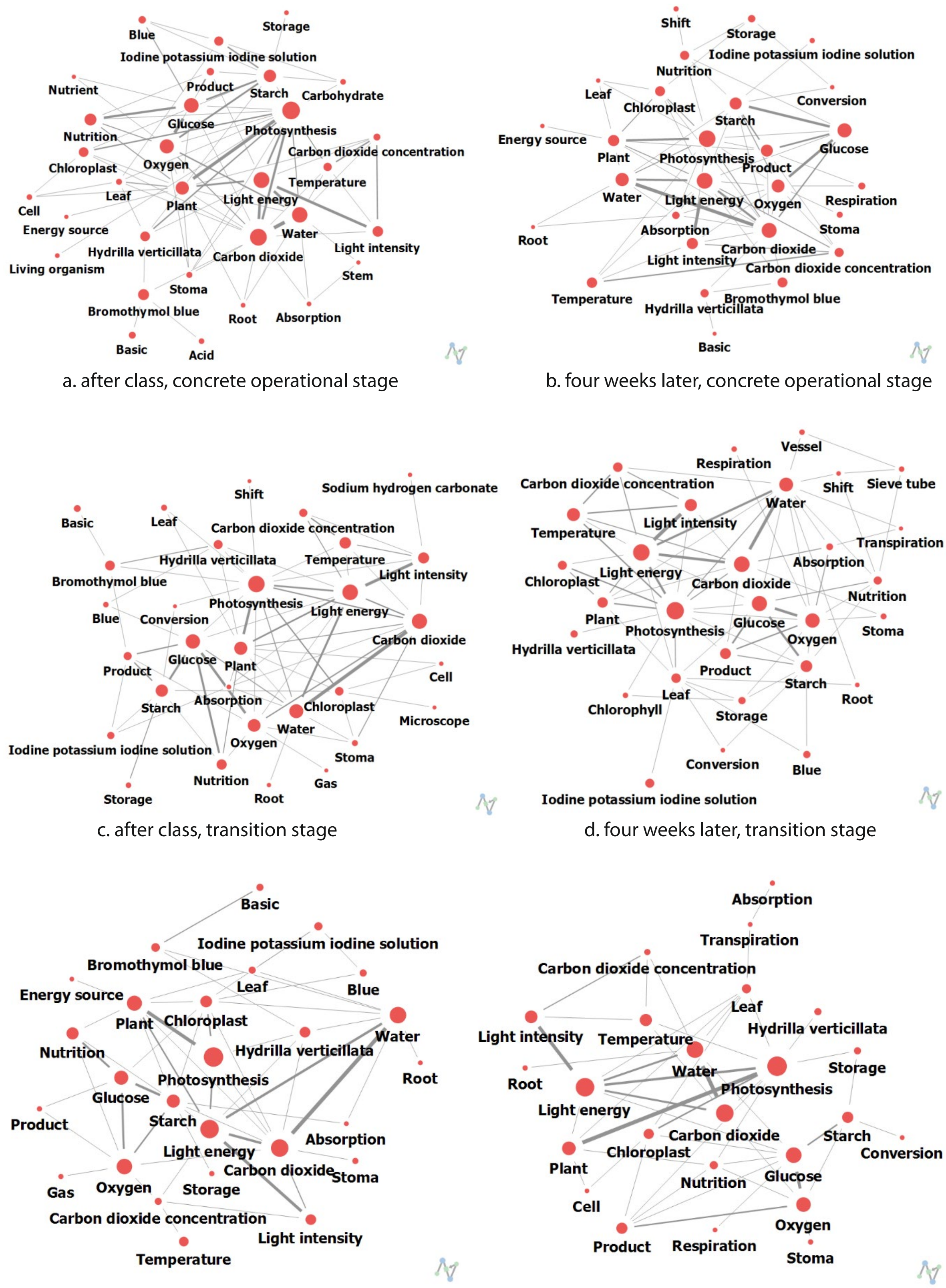
Figure 4

'Photosynthesis' Concept Networks based on Cognitive Level



a. after class, concrete operational stage

b. four weeks later, concrete operational stage

c. after class, transition stage

d. four weeks later, transition stage

e. after class, formal operational stage

f. four weeks later, formal operational stage

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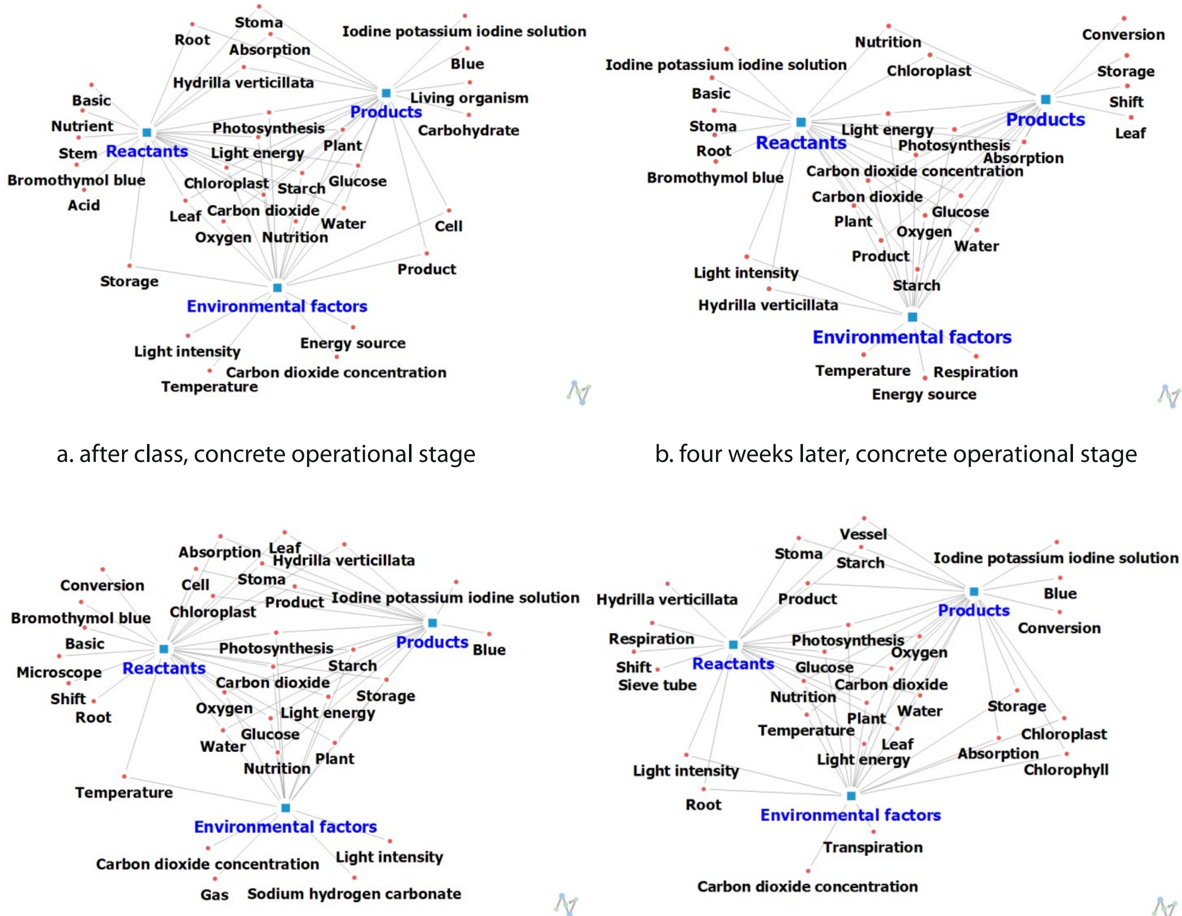
Connection Concept Networks

Connection Concept Networks between Subtopics

The connected concepts for each photosynthesis subtopic were analyzed based on cognitive levels (Figure 5). Among students in the concrete operational stage, 11 concept subtopics were commonly identified after the initial class, including "photosynthesis," "light energy," "plants," "chloroplasts," and "carbon dioxide" (Figure 5a). Four weeks later, 11 concepts, including "photosynthesis," "light energy," "absorption," and "carbon dioxide concentration," were identified (Figure 5b). For students in the concrete operational stage, "carbon dioxide concentration" was only connected with 'environmental factors' after the initial class, but four weeks later, it was commonly linked to three subtopics. "Iodine-potassium iodide solution" was linked to 'photosynthesis products' after the initial class but was linked with 'photosynthesis reactants' four weeks later.

Figure 5

Connection Concept Networks between Subtopics



a. after class, concrete operational stage

b. four weeks later, concrete operational stage

c. after class, transition stage

d. four weeks later, transition stage

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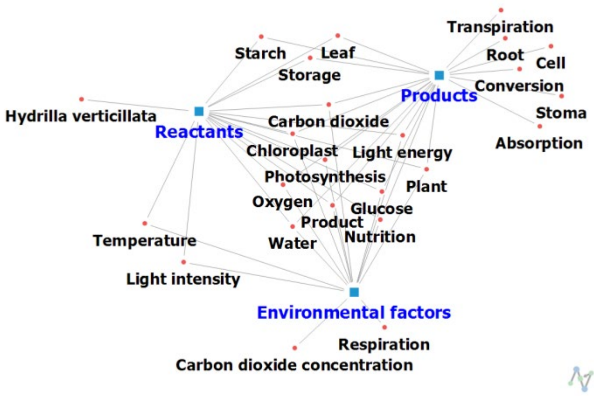
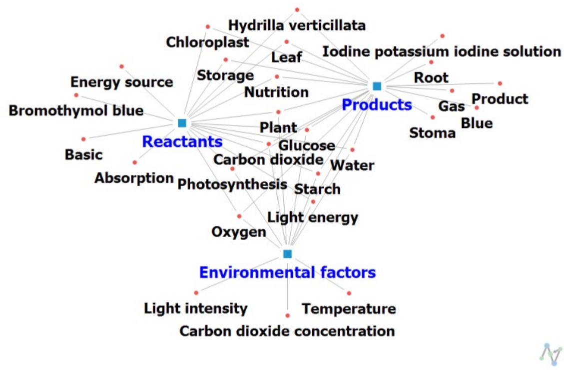


e. after class, formal operational stage



f. four weeks later, formal operational stage

After the initial class, students in the transition stage identified ten connected concepts within the subtopics, including "photosynthesis," "glucose," "carbon dioxide," and "plants" (Figure 5c). Four weeks later, ten concepts, including "photosynthesis," "oxygen," "glucose," and "temperature," were connected (Figure 5d). Students in the transition stage differed from those in the concrete operational stage in that they only connected the concept of "carbon dioxide concentration" with 'environmental factors' after the initial class and four weeks later.

Additionally, after the initial class, students in the formal operational stage identified and connected eight concepts, including "photosynthesis," "carbon dioxide," "glucose," and "water," with the subtopics (Figure 5e). Four weeks later, ten concepts, including "oxygen," "production," and "photosynthesis," were connected (Figure 5f). Students in the formal operational stage lost concepts related to inquiry activities, such as "bromothymol blue," "iodine-potassium iodide solution," and "blue" after four weeks of class. Through this, it can be inferred that it is developed within the cognitive structure by focusing on the concept itself rather than inquiry activity-related concepts.

Connection Concept Networks between Subtopics and Cognitive Levels

For each photosynthesis subtopic, the concepts connected by students were structured according to cognitive level (Figure 6). In the subtopic 'photosynthesis reactants' (Figures 6a and b), there were 15 concepts that students at all cognitive levels had in common after the initial class, including "carbon dioxide," "absorption," "storage," and "bromothymol blue." Four weeks later, there were 12 concepts, including "carbon dioxide," "hydrilla verticillata," "nutrition," and "oxygen." After class, students in the concrete operational stage learned three concepts, students in the transitional stage learned six concepts, and students in the formal thinking stage learned only one concept. After four weeks of class, five concepts were identified by students in the concrete operational stage, students in the transitional stage identified four concepts, and one concept was identified by students in the formal operational stage.

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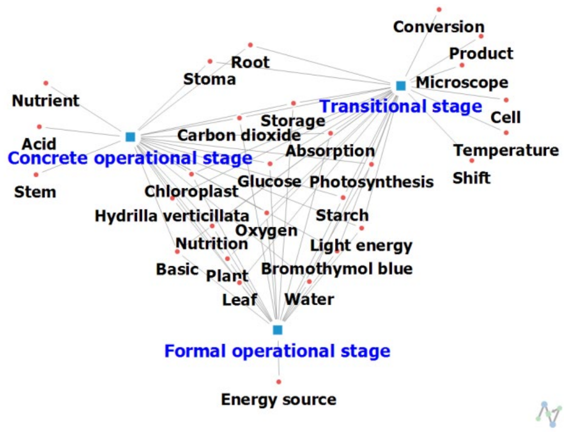
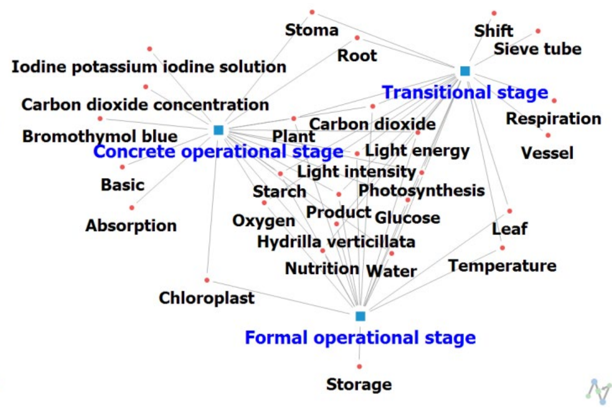
Figure 6

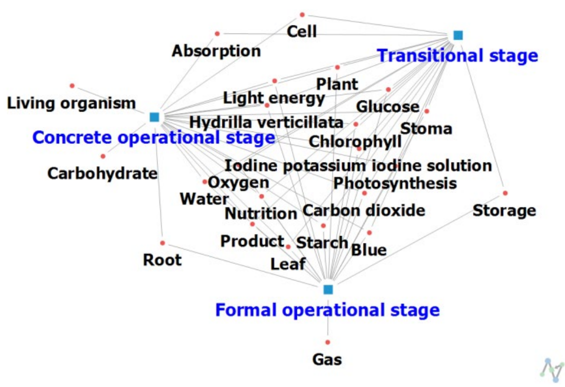
Connection Concept Networks between Cognitive Levels



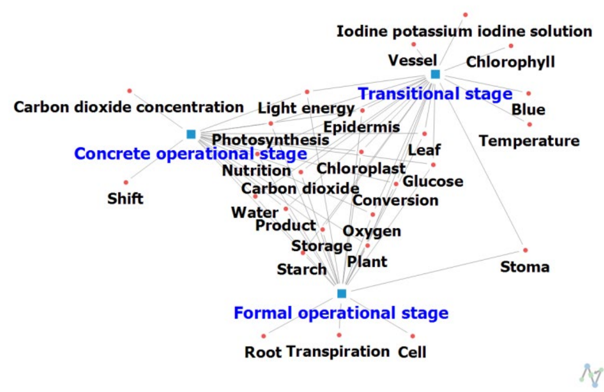
a. after class, photosynthesis reactants



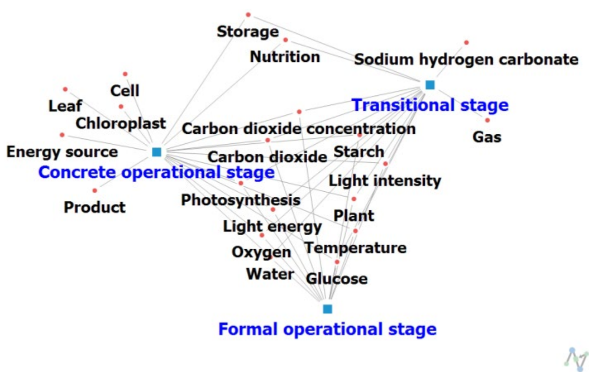
b. four weeks later, photosynthesis reactants



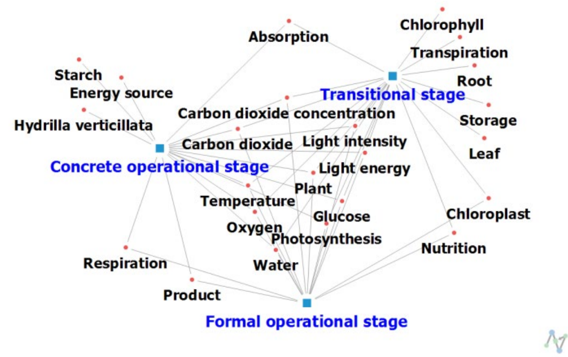
c. after class, photosynthesis products



d. four weeks later, photosynthesis products



e. after class, environmental factors



f. four weeks later, environmental factors

In the subtopic "photosynthesis products" (Figures 6c and d), students at all cognitive levels commonly identified 16 concepts including "hydrilla verticillata," "photosynthesis," "starch," "water," and "light energy" after the initial class. After four weeks of class, students at all cognitive levels commonly identified 15 concepts, including "starch," "photosynthesis," "oxygen," and "light energy." Meanwhile, after class, students in the concrete operational stage identified two concepts, and students in the formal operational stage identified one. After four weeks of class,

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students in the concrete operational stage identified one concept, students in the transitional stage identified five, and students in the formal operational stage identified three.

For the subtopic "environmental factors" (Figures 6e and f), the concepts that students of all cognitive levels had in common after the initial class and four weeks later were "photosynthesis," "water," "light energy," "light intensity," "oxygen," "plant," and "carbon dioxide concentration." Eleven common concepts were identified after the initial class, and ten were identified four weeks later. The difference is that "starch" was commonly identified only after the initial class. Meanwhile, after the initial class, students in the concrete operational stage identified five concepts, and students in the transition stage identified two. After four weeks of class, students in the concrete operational stage identified three concepts, and students in the transition stage identified five, confirming that students in the formal operational stage only understood core concepts. In addition, this verified that the higher the cognitive level, the more students learned scientific concepts.

Discussion

In this study, the concept and connected concept networks were analyzed depending on students' cognitive structures after classes based on three photosynthesis subtopics, 'photosynthesis reactants,' 'photosynthesis products,' and 'environmental factors.' The photosynthesis learning concept questionnaires were analyzed twice: immediately after the initial class and four weeks later. As a result of the analysis, depending on students' cognitive levels, there was no significant difference in the number and type of learning concepts students acquired after class and four weeks later, but there was a difference in the concept network structure.

Regarding concepts related to photosynthesis, students at all cognitive levels commonly recognized the concepts of "photosynthesis," "plants," "water," "light energy," "oxygen," "carbon dioxide," and "glucose" (Figure 5). The concepts cover all important topics related to photosynthesis, and the key concepts for each subtopic were strongly connected. For example, in the case of "environmental factors," it was confirmed that the concepts of "light intensity," "carbon dioxide concentration," "temperature," and "photosynthesis" were robustly linked among students at all cognitive levels (Figure 3).

Meanwhile, students found that their subsequent learning influenced the formation and structuring of concepts formed by prior learning. For example, after four weeks of class on 'photosynthesis reactants,' the concept of "carbon dioxide concentration" was presented. Through this, it was confirmed that the concepts learned through subsequent learning were structured together with those of prior learning.

Students in the concrete operational stage had difficulty differentiating between similar concepts. In the case of 'environmental factors,' students initially connected "photosynthesis" with "light energy," "carbon dioxide," and "temperature" but did not make the connection with "light intensity" or "carbon dioxide concentration," which are similar but more detailed concepts. Even four weeks later, this phenomenon continued. The network seemed to only connect the similar concepts of "light energy" and "light intensity." In addition, students in the concrete operational stage could not clearly distinguish the relationship between concepts. For example, "iodine-potassium iodide solution," presented as an inquiry activity to check the substances produced from photosynthesis, is recognized as a necessary rather than produced substance after four weeks of class. Therefore, it can be inferred that students failed to connect concepts and subtopics related to inquiry activities. It is known that students have difficulty learning because the content about photosynthesis is an invisible phenomenon, contains abstract elements, and consists of connections between complex concepts (Marrnaroti & Galanpoulou, 2006). Accordingly, it is more likely that students in the concrete operational stage will experience more difficulties in learning. Therefore, for them, a teaching and learning strategy that clearly distinguishes similar terms and chunks them can clarify their relevance (Kim et al., 2023).

In the formal operational stage, students distinguished concepts more clearly than at other cognitive levels. However, they tended to focus more on concepts rather than engaging in inquiry activities. For example, even after four weeks of classes on "photosynthesis reactants," students were unable to identify concepts related to inquiry activities such as "iodine-potassium iodide solution," "bromothymol blue," "hydrilla verticillata," and "blue." Although the teachers explained the concept focusing on the inquiry activity (Kim et al., 2023), students in the formal operational stage seemed to learn primarily based on the concept, deviating from the teacher's explanation. This could be attributed to the ease with which students can explain phenomena using scientific concepts (Cochran-Smith & Lytle, 1999; Duit & Treagust, 2003).

In the three photosynthesis subtopics, the concepts that students at all cognitive levels connected were "photosynthesis," "water," "light energy," "oxygen," "plants," "carbon dioxide," and "glucose." These concepts correspond with 'photosynthesis reactants' (light energy, water, carbon dioxide) and 'photosynthesis products' (oxygen, glucose). This

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confirms that students' understanding of photosynthesis focuses on the materials and products required, which is believed to be because photosynthesis has already been learned in the 'Structure and Function of Plants' unit in elementary school (MOE, 2015). And, this indicates that 'environmental factors,' first taught in lower secondary school, were not learned properly. To solve scientific problems, students need to understand many concepts. To achieve this, students should be able to expand their understanding by connecting their prior concepts, the concepts they are currently learning, and the concepts they will learn in the future. However, it is known that students have the most difficulty making connections between concepts, which are essential for learning (Ibáñez & Martinez-Aznar, 2005). To help make these connections, teachers need to present concepts commonly recognized by students of all cognitive levels (e.g. "photosynthesis," "water," "light energy," "oxygen," "plant," "carbon dioxide," and "glucose") by structuring them into subtopics. If the curriculum is presented by structuring the content knowledge into core concepts, it can help students understand by showing them the systematic structure of biology (Kinchin, 2011). In this way, it is thought that it will be helpful in learning concepts related to photosynthesis if subtopics and concepts are structured and presented using learning concepts in the taught curriculum.

Conclusions and Implications

This study aimed to analyze 8th-grade students' concepts and connected concept networks based on their cognitive level after an initial class on photosynthesis and four weeks later. The conclusions are as follows. First, students at all cognitive levels could not clearly distinguish each subtopic's concepts. Accordingly, they identified concepts that were not directly related to subtopics.

Second, regardless of their cognitive level, students understood the concept of photosynthesis with a focus on reactants and products. Regarding the photosynthesis subtopics, the concepts students commonly learned after the initial class and four weeks later were "photosynthesis," "water," "light energy," "oxygen," "plants," "carbon dioxide," and "glucose." This is based on what students have learned in the previous curriculum; thus, there is a need to connect and chunk concepts that have already been learned and new concepts.

Third, depending on students' cognitive levels, there was no significant difference in the number and type of learning concepts they acquired after class and four weeks later, but the concept network structure differed. Students commonly recognized several key concepts related to photosynthesis, including "photosynthesis," "plants," "oxygen," "water," "light energy," "carbon dioxide," and "glucose." However, there were differences in how these concepts were linked in the concept network. Students in the transition stage showed that concepts related to inquiry activities were linked to form a network. Students in the formal operational stage could reorganize their concept network by focusing on specific concepts. In addition, students in the formal operational stage not only frequently identified these key concepts compared to students at other cognitive levels but also had a high eigenvector index in connection with other concepts, occupying a central position in the concept network.

Fourth, after four weeks, there were differences in the presented concepts and the structure of the concept network depending on the cognitive level. For example, concepts learned later were included, and concepts related to inquiry activities disappeared. Therefore, due to various factors such as newly learned content and retained information four weeks later, students cognitively restructured their knowledge into a form that was easier to understand.

Thus, students in the concrete operational stage were less able to clearly distinguish similar concepts when learning photosynthesis and related concepts were not properly linked. Additionally, those in the formal operational stage tended to engage in cognitive restructuring by focusing on the concept itself. Therefore, teachers must clearly distinguish similar concepts by considering students' cognitive levels and present related concepts in chunks. In addition, concepts related to inquiry activities and newly presented concepts must be taught in relation to concepts that students already know.

Limitations of the Study

This study has some limitations. First, the participants of this study received traditional lecture-based teaching in the Republic of Korea. Therefore, in future studies, there is a need to analyze learning concepts in various types of teaching methods, such as inquiry activities and discussions. Secondly, a questionnaire was used to analyze the learning concepts of these students. This has the limitation that only concepts limited to the questionnaire can be presented. To complement this, a more in-depth analysis of the learning concept network can be performed through the process of visualizing the concepts presented by students as a network using think-aloud in the process of solving problems.

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Declaration of Interest

The authors declare no competing interest.

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